Modeling evaporation from porous medium influenced by turbulent free flow

International Research Training Group nupus

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Motivation

This project focuses on understanding and modeling the relevant processes of evaporation.
Evaporation is strongly influenced by the interaction of different physical processes and properties

- in the free flow
- at the interface
- inside the porous medium

In a preliminary work, the coupling of those two flow regimes has been performed [1, 3].

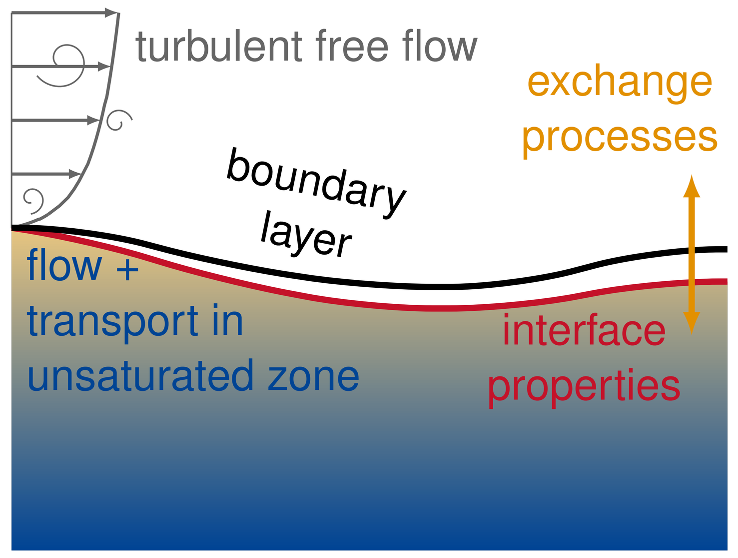

Figure 1: *Relevant processes for modeling evaporation from bare soil on a field scale.*

The main goal is to increase the predictability of evaporation rates under turbulent conditions. Within this work, the knowledge is transferred from laboratory to field scale.

Physics

Boundary Layer

For bounded flow with friction, a thin, viscous-dominated layer near the porous-medium-free-flow interface is limiting flow and transport.

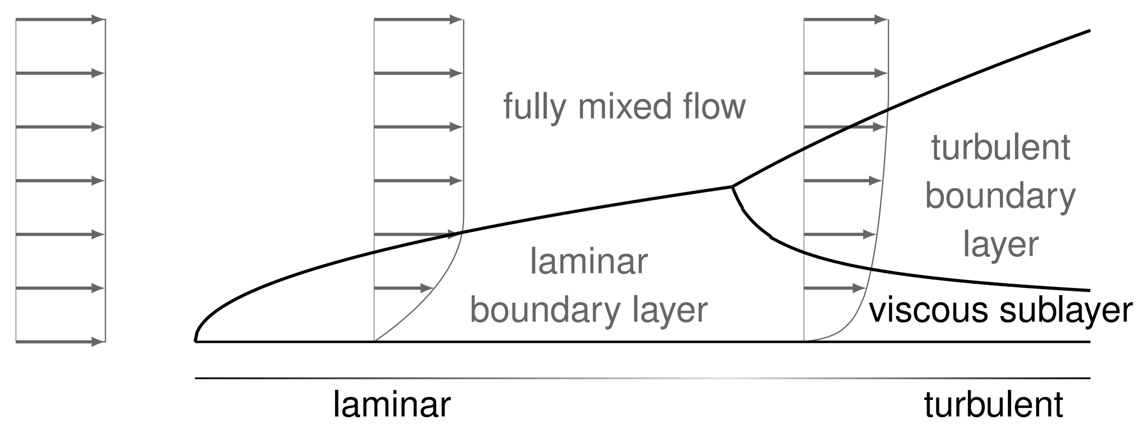

Figure 2: *Boundary layer evolution along a flat and impermeable wall.*

Flow and transport processes

Various processes and phenomena are contributing to the evaporation process and have to be considered in the model.

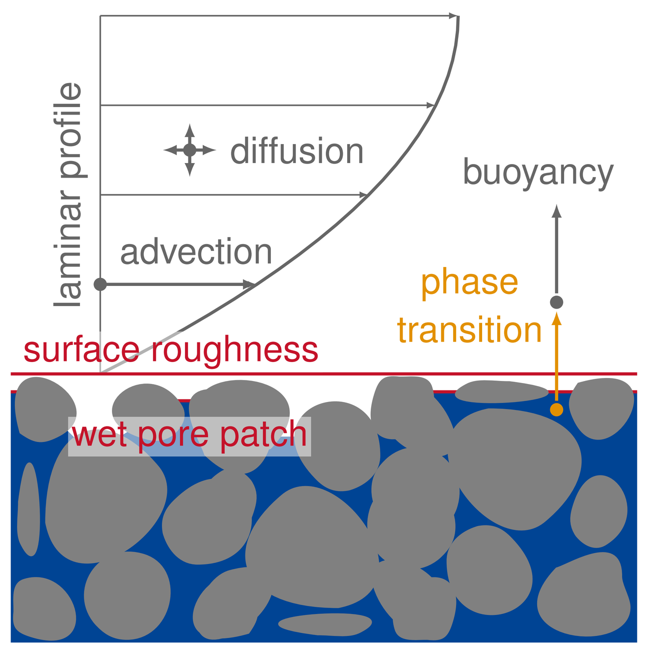

Figure 3: *Flow and transport in an isothermal, laminar flow.*

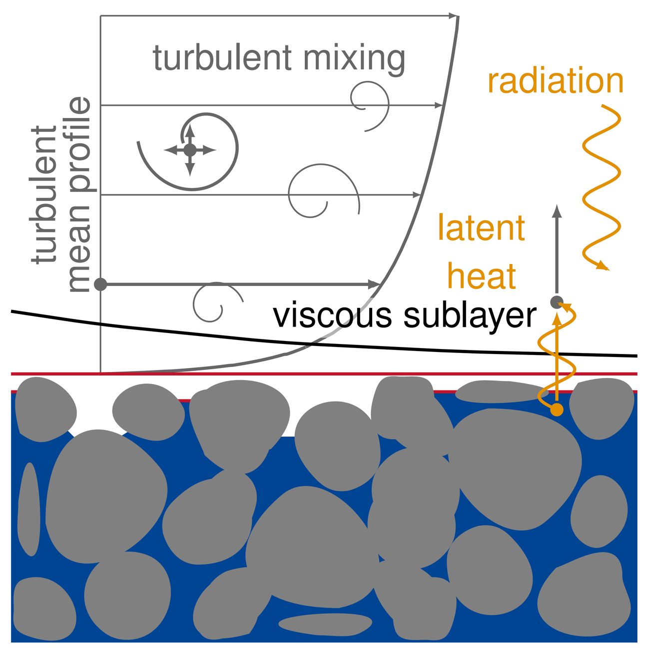

Figure 4: *Flow and transport in a non-isothermal, turbulent flow.*

Model concepts

Coupling

- 1 domain, [2]
- 1 set of equations
- transition zone

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- 2 domains, [1, 3]
- 2 different set of equations
- sharp interface

Model toolbox

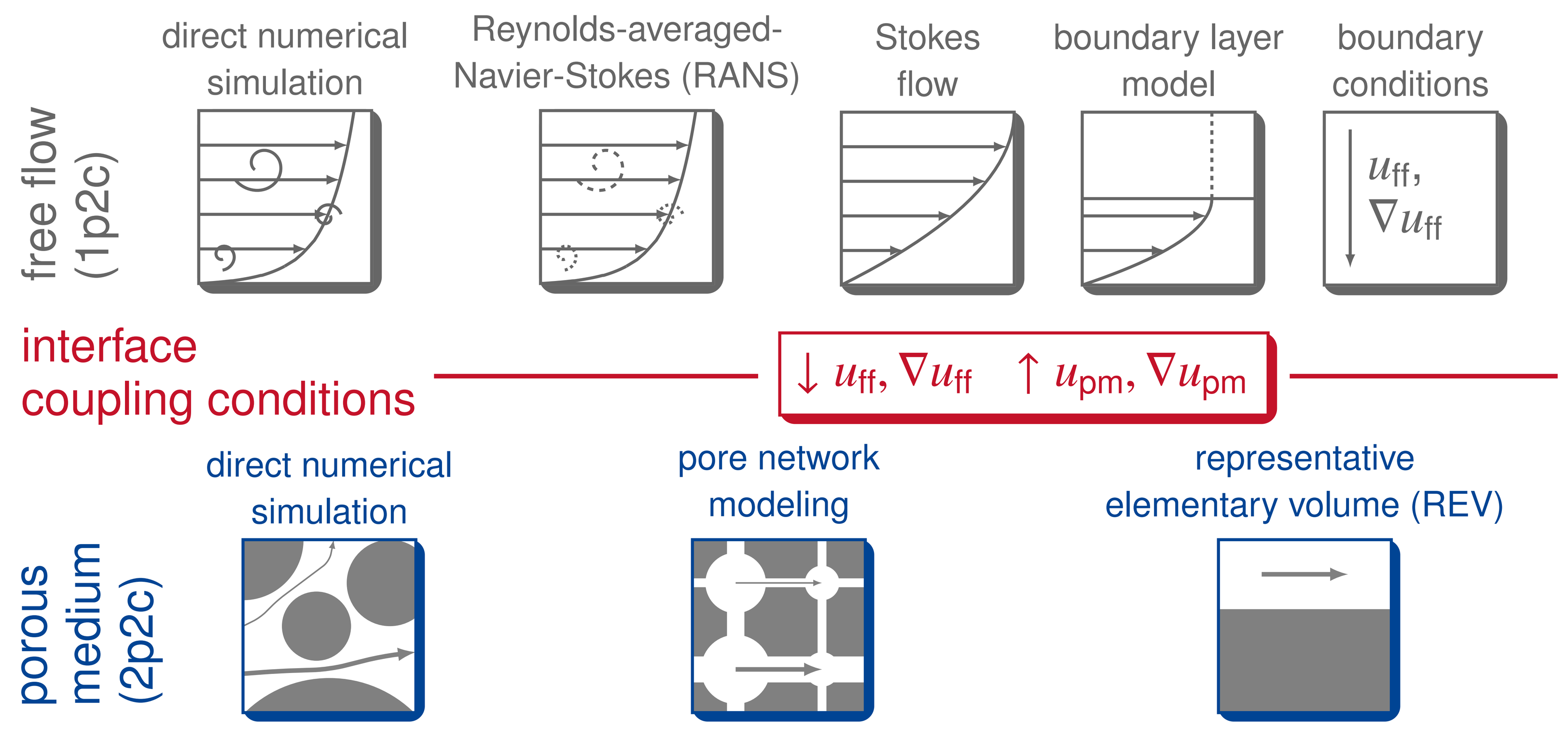

Figure 5: *Different methods for modeling free and porous-medium flow. The free flow is considered as a one-phase, two-component system (1p2c), the porous medium as a two-phase, two-component system (2p2c).*

Experiment

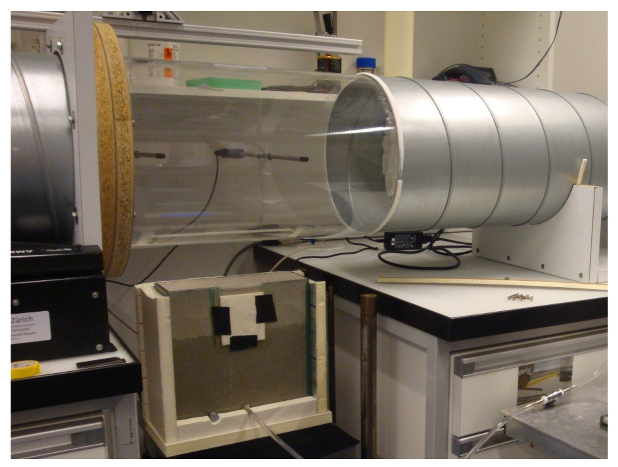

Figure 6: *Setup of the experiments done in cooperation with ETH Zürich, [4].*

free flow	
wind speed	$3.5\ ^{m}/_{s}$
pressure	$1 \cdot 10^5$ Pa
porous medium	
permeability	$3.2 \cdot 10^{-10}\ m^2$
porosity	0.4
min. grain diameter	0.3 mm
max. grain diameter	0.9 mm

Table 1: *Parameters of the experiment.*

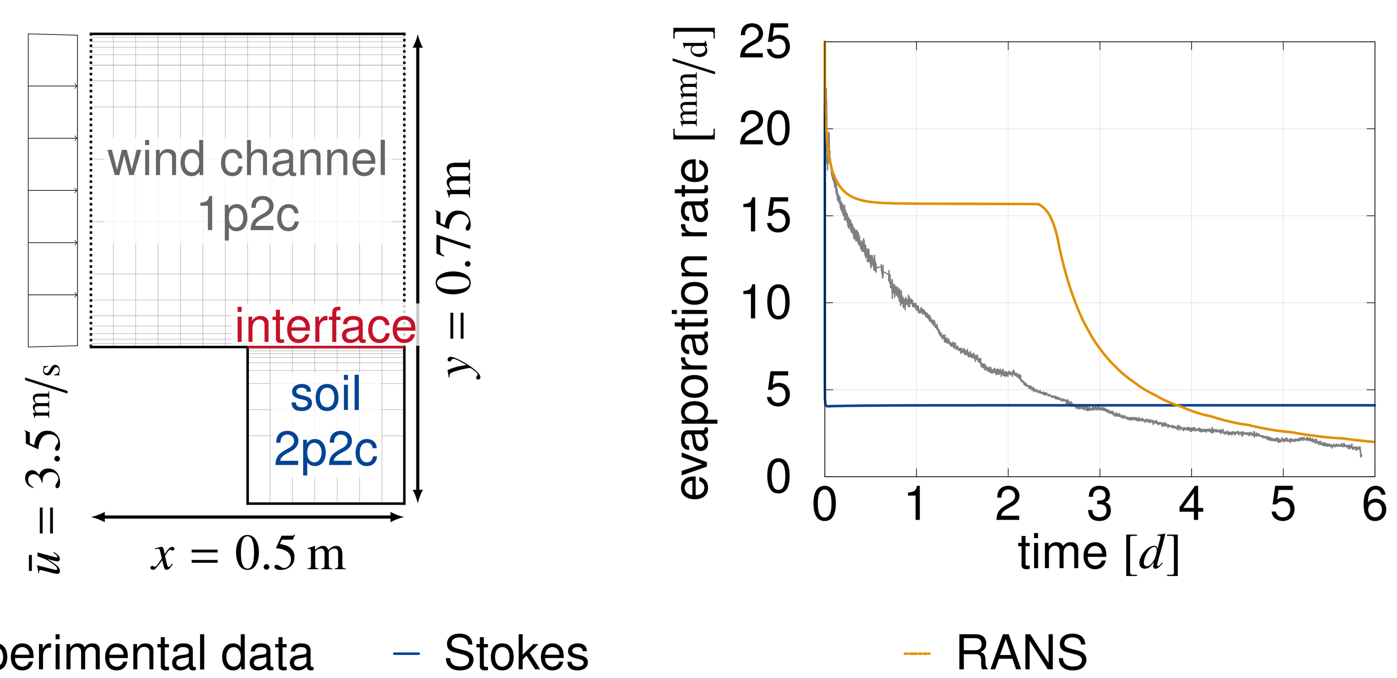

Figure 7: *Setup of the non-isothermal simulations and calculated evaporation rates.*

Results

Results

- turbulent free flow improves results
- viscous sublayer is important
- wet pore patch influences evaporation rate

Challenges

- 3D effects
- pressure oscillations
- high computational effort
- no grid convergence

Outlook

Model concept

Goal: Stable discretization and fast solution for turbulence flow over more complex geometries.

- implementation of k-ω turbulence model and wall functions
- staggered grid for structured and unstructured grids
- multiple timestepping methods
- mortar elements at coupling interface
- coupling and testing of different model concepts
- extension to 3D

Experiment

Goal: Validation of the model concept.

- Lattice Boltzman simulation for flow in a soil sample
- more detailed wind channel experiments

Field scale

Goal: Simulation of real problems on larger scales.

- upscaling of results and parameters
- including new processes and parameters occurring on field scale
- reduction of model complexitiy

Literature

[1] K. Baber, K. Mosthaf, B. Flemisch, R. Helmig, S. Müthing, and B. Wohlmuth. "Numerical scheme for coupling two-phase compositional porous-media flow and one-phase compositional free flow". *IMA Journal of Applied Mathematics*, 77, 2012.

[2] H. C. Brinkman. "A calculation of the viscous force exerted by a flowing fluid on a dense swarm of particles". *Applied Scientific Research*, 1, 1949.

[3] K. Mosthaf, K. Baber, B. Flemisch, R. Helmig, A. Leijnse, I. Rybak, and B. Wohlmuth. "A coupling concept for two-phase compositional porous-medium and single-phase compositional free flow". *Water Resources Research*, 47, 2011.

[4] E. Shahraeeni, P. Lehmann, and D. Or. "Coupling of evaporative fluxes from drying porous surfaces with air boundary layer: Characteristics of evaporation from discrete pores". *Water Resources Research*, 48, 2012.

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Simulations are performed using the open-source simulator DuMu[x].

This study is done in cooperation with the research unit MUSIS.